DE-FE 0009469

Solid-Fueled Pressurized Chemical Looping with Flue-Gas Turbine Combined Cycle for Improved Plant Efficiency and CO_2 Capture

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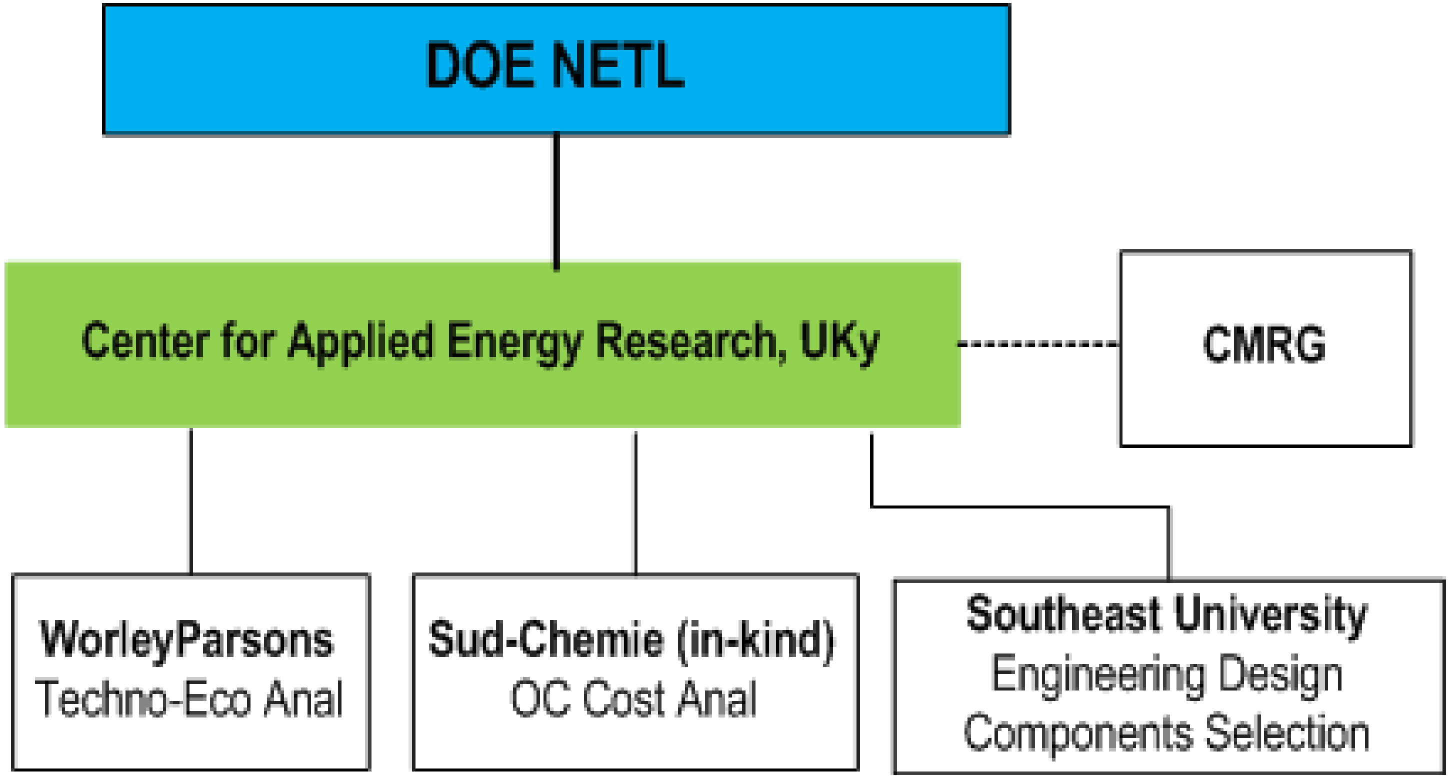
Outline

- Team members
- Technology/Technical Approach
- Project Objective
- Finding from CLC Research at UKy and SEU
- Proposed Tasks
- Phase 2 Approach
- Schedule and Budget

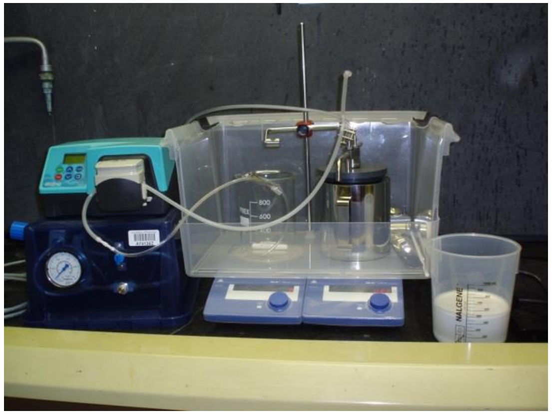
Team Structure



University of Kentucky CAER

- Three decades of clean coal research;
- Existing programs for CO_2 capture and advanced power generation technologies;
- Leading position on catalyst, material development;
- Extensive experience with coal conversion technologies;
- Word class research institute for coal related issues.

Instruments and Equipment for CLC




TGA/DSC/DTA/MS with WV Furnace

Hitachi S-4800

Philips X'pert

CAER Bench-scale Redox

Bench Scale reactor and operating -controlling system

Southeast University, China

- ✓ Pioneer in the field of PFBC technology of coal combustion/gasification
- ✓ More than 30 years experience on FBC technology;
- ✓ Extensive experiences in power plant design, system integration and PFBC-CC power generation.

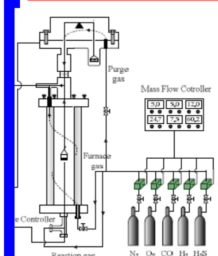
- **1 MW PFBC test facility (PI is team lead)**
- **2 WM pressurized spout-fluid bed coal gasifier for 2G PFBC-CC**
- **15 MW PFBC-CC plant for demonstration (at Xuzhou, China);**
- **2.5 MW FBC unit for oxy-fuel combustion**

CLC Technology Development at SEU

Scale up

Gas	CH$_4$, syngas	Coal	Coal, Biomass	Coal
2002~2009	2002~2009	2004~2009	2002~2009	2009~2011

TGA



Gas

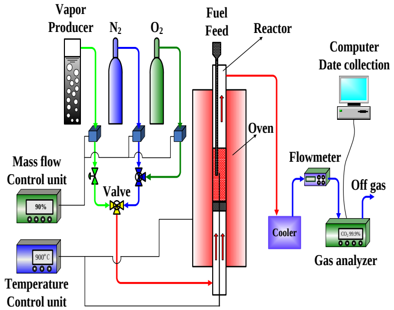
2002~2009

Fixed, fluidized bed

CH$_4$, syngas

2004~2009

1KW Fluidized bed



Coal

2002~2009

10 kWth CLC

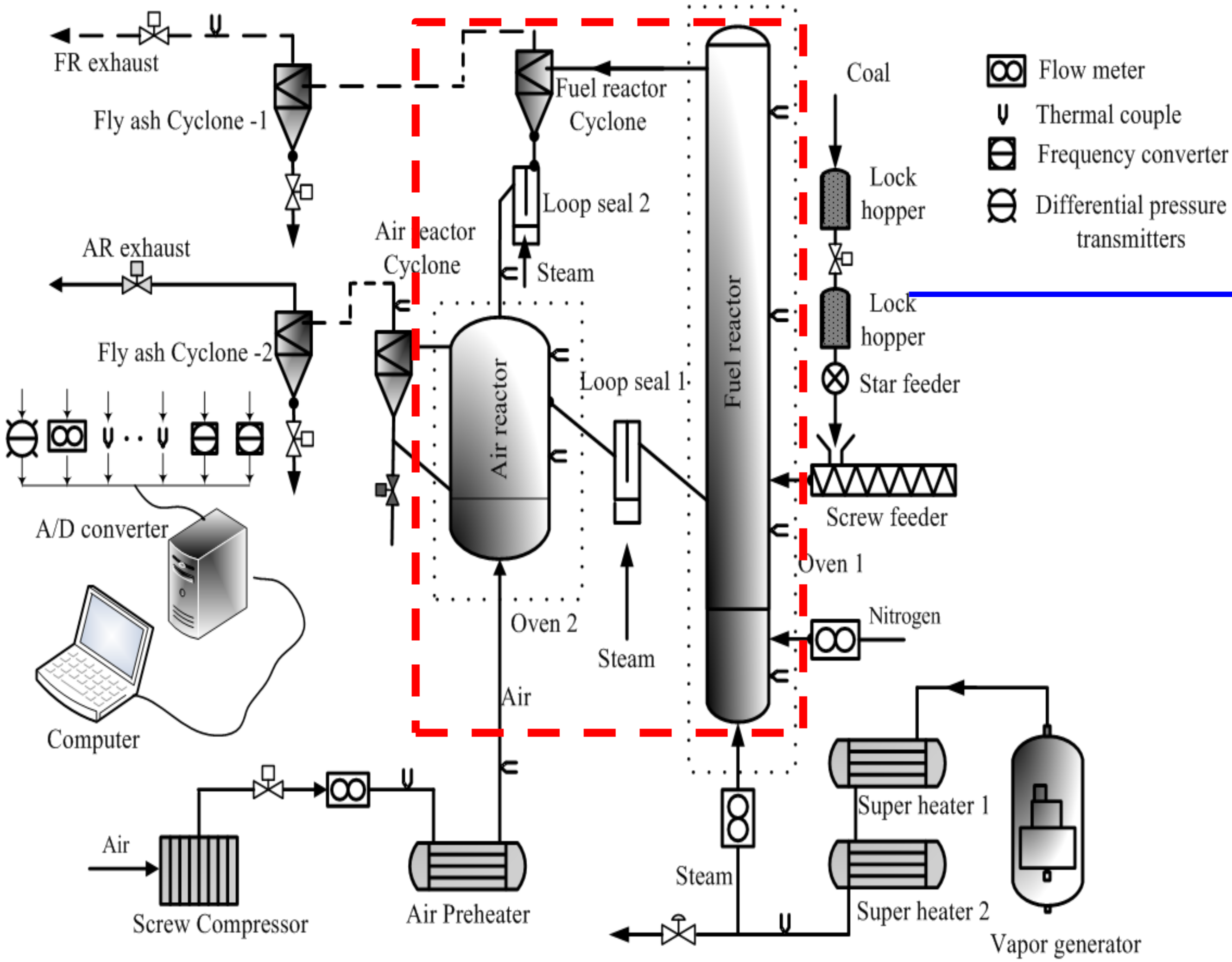
Coal, Biomass

2009~2011

100 kWth Continuous CLC

Coal

100 kW PCLC Unit at SEU



DE-FE 0009469 Project Objectives

(1) To develop an advanced high-efficiency, advance coal-based technology for future power generation with CO_2 capture;

(2) To demonstrate an advanced coal-based power generation technology to potentially meet DOE's target on CO_2 capture.

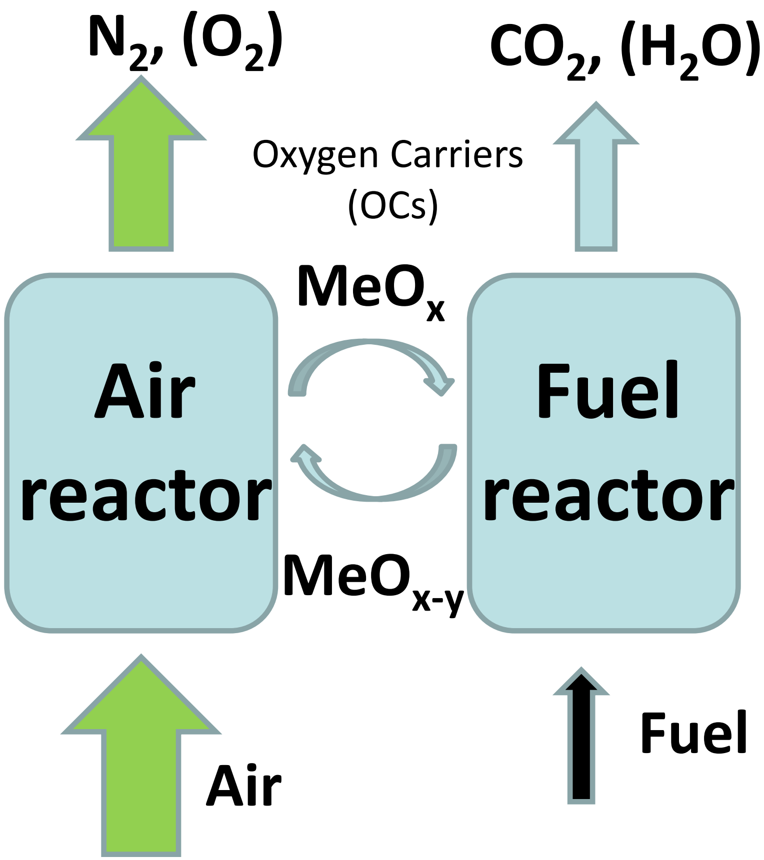
(3) To gather and determine the reaction kinetics and the durability of OC to design and construct a pilot-scale apparatus;

(4) To size the major equipment and conduct techno-economic analysis using data obtained from TGA, bench-scale and pilot-scale apparatus operated at CAER and Southeast University.

Approach to Achieve the Objectives

- ➢ Combined cycle
- ➢ Cost-effective oxygen carrier
- ➢ Pre-compression in redox
  - Pre-pyrolysis for tar remove
  - CFBC (Oxidizer) + BFBC & MB (Redox)
  - Elimination of internal heat exchanger

Chemical Looping Combustion



- One type of oxy-combustion processes
- In-situ oxygen separation instead of stand alone air separation units
- Generate high purity CO_2 stream at the fuel reactor exhaust

- Air reactor

$$Me_xO_{y-z} + \tfrac{z}{2}O_2 \rightarrow Me_xO_y$$

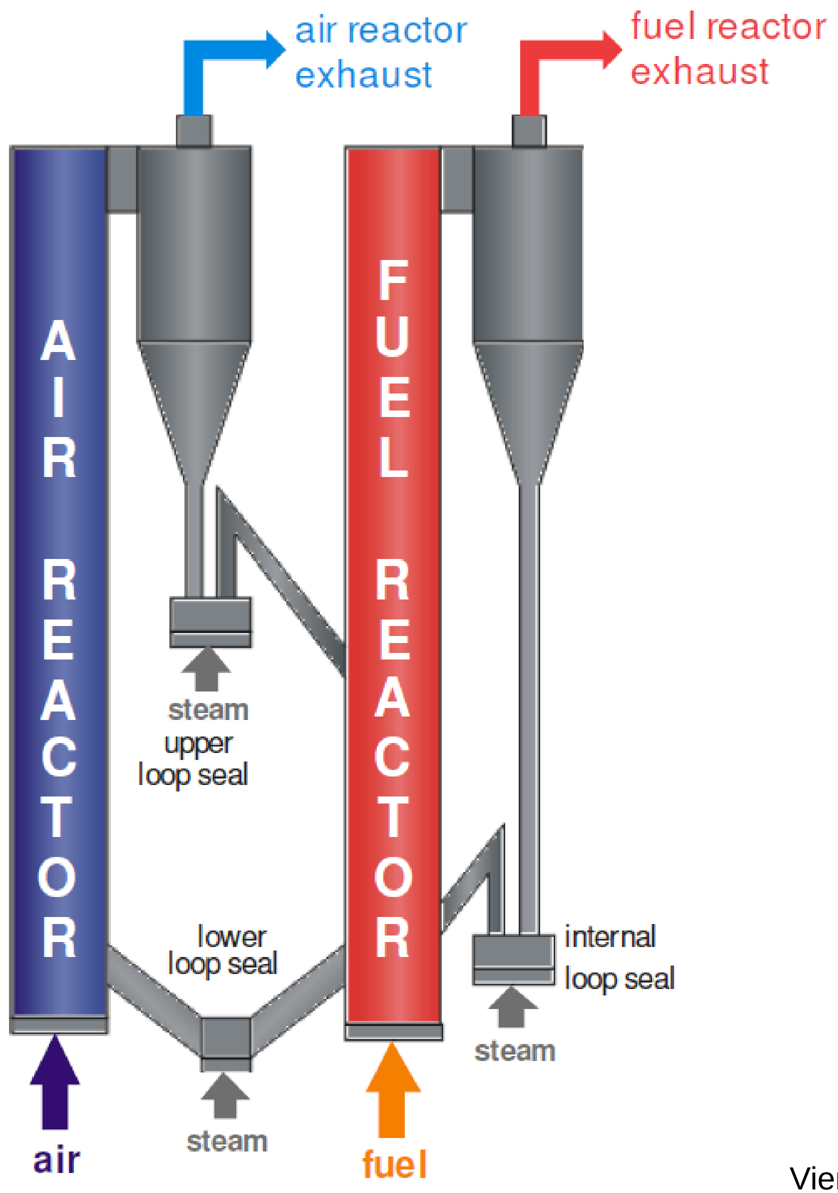
- Fuel reactor

$$Me_xO_y + \tfrac{z}{2}C \rightarrow Me_xO_{y-z} + \tfrac{z}{2}CO_2$$

- Overall

$$C + O_2 \rightarrow CO_2$$

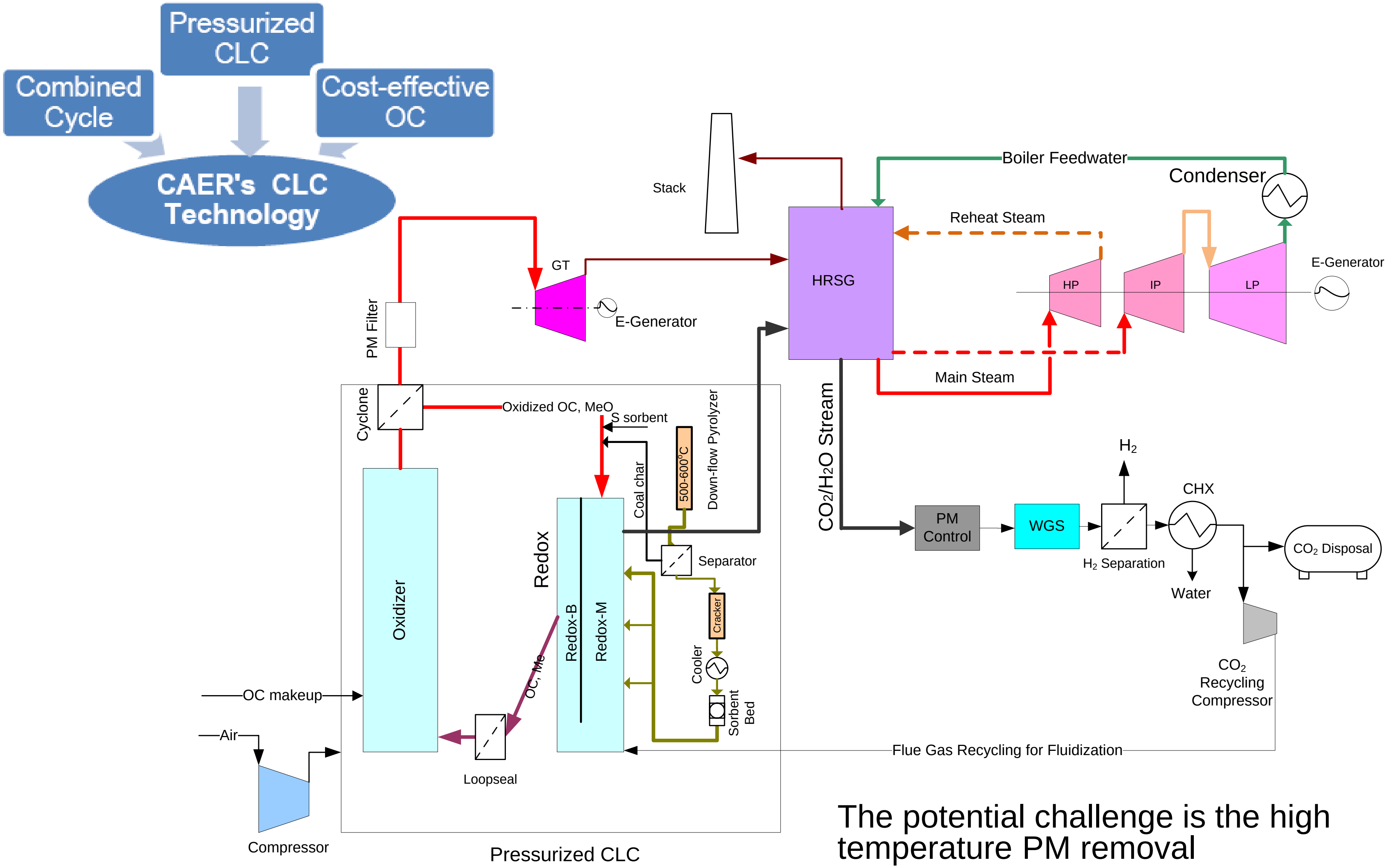
Example:
Fluidized Bed Reactor for Gaseous Fueled-CLC



Technical Hurdles for Solid Fuels

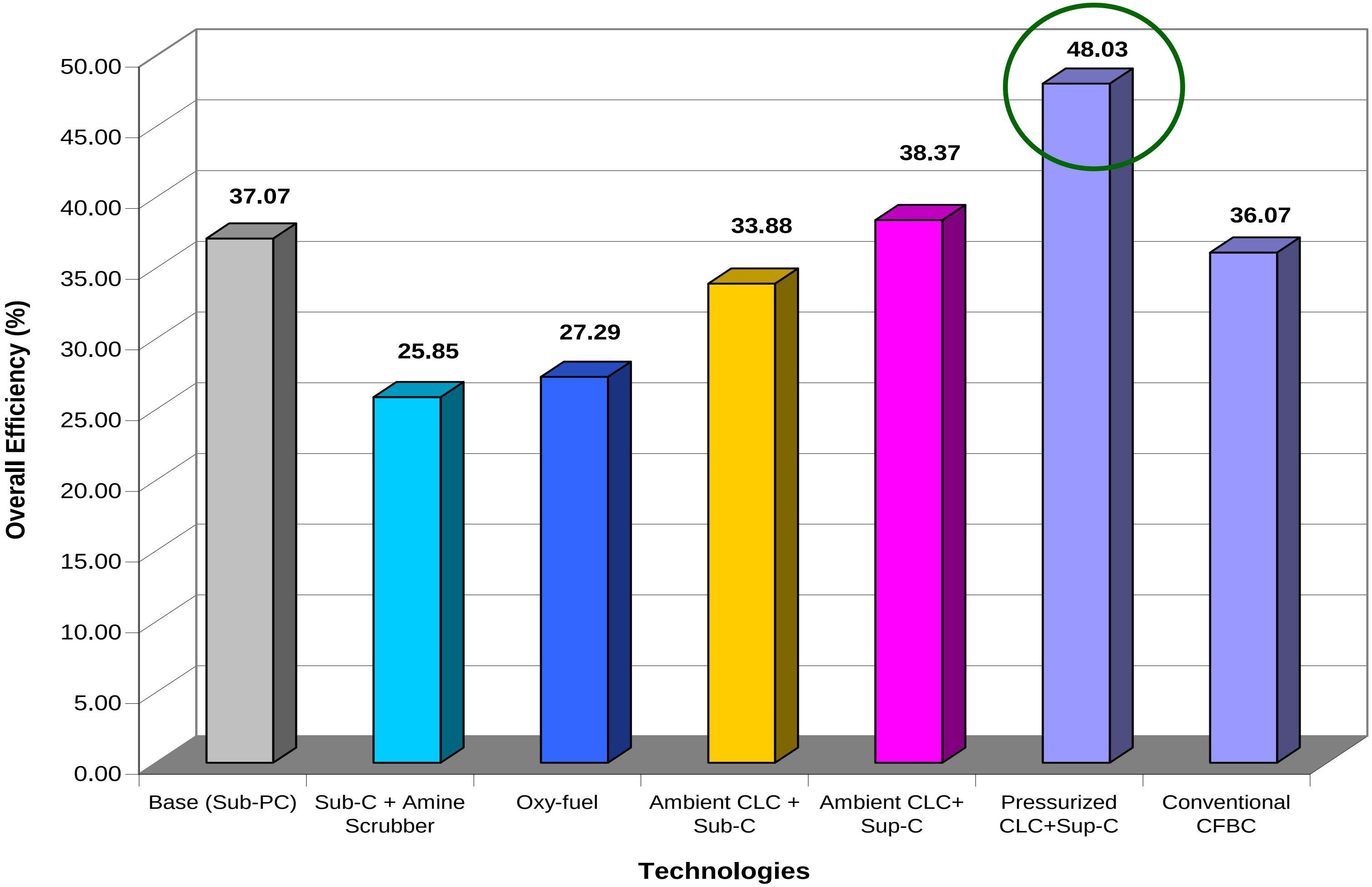
- Tar production, oxygen carrier agglomeration
- Slow reaction rate between Solid fuel – Solid oxygen carrier
- Separation of oxygen carrier from fuel and ash particles
- Possible interaction between the fuel mineral matter and oxygen carrier
- The lack of free oxygen for combusting solid fuel particles
- The combustion of unburned carbon particles in the oxidizer due to the circulation of solid fuel particles from the reducing reactor to the oxidizing reactor
- Char carryover to oxidizer cause loss of CO_2 efficiency

System We Proposed



The potential challenge is the high temperature PM removal

Advantages of CAER Process



Effort on OC Development at CAER

Criteria of Successful OC

Reactive requirement
- ✓High Red-Ox reactivity
- ✓High oxygen transport capacity
- ✓High Stability

Requirement for Power Generation
- ✓Cost-Effective
- ✓Low fragmentation & attrition
- ✓Low tendency for agglomeration
- ✓High heat capacity
- ✓Appropriate fluidization property

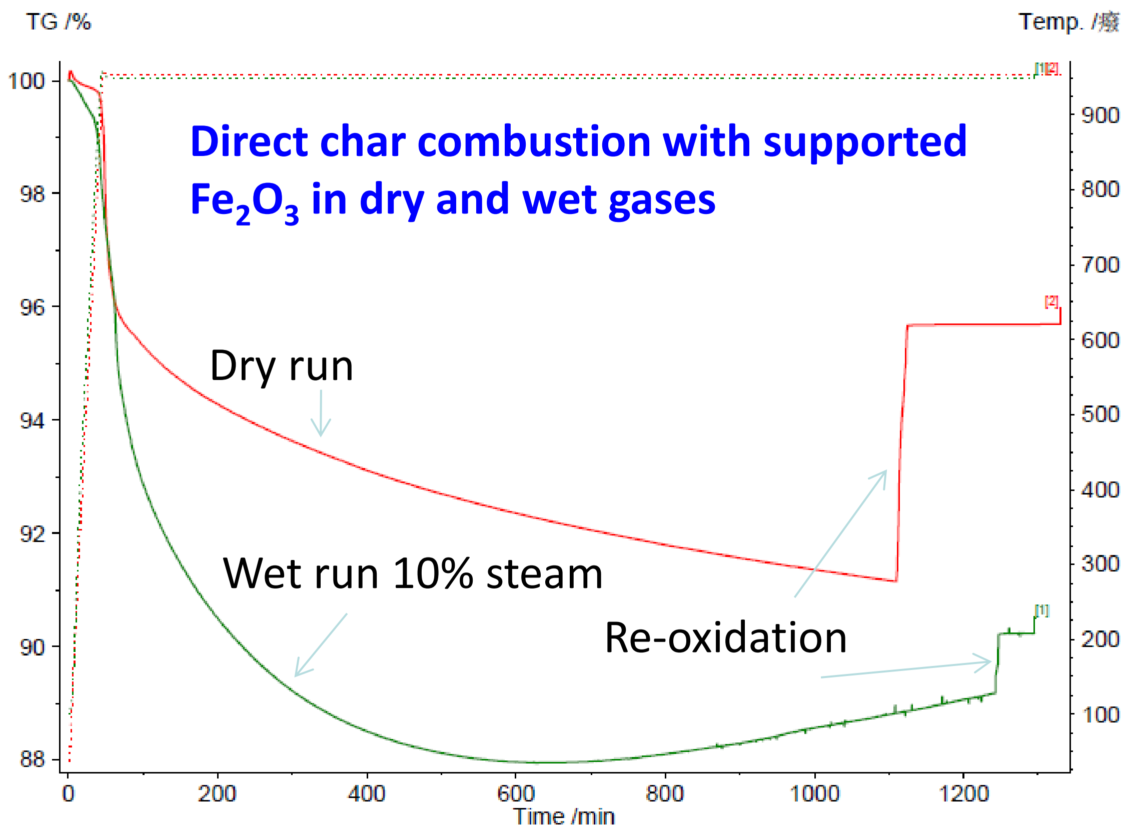
Iron-based OC for coal-fueled CLC

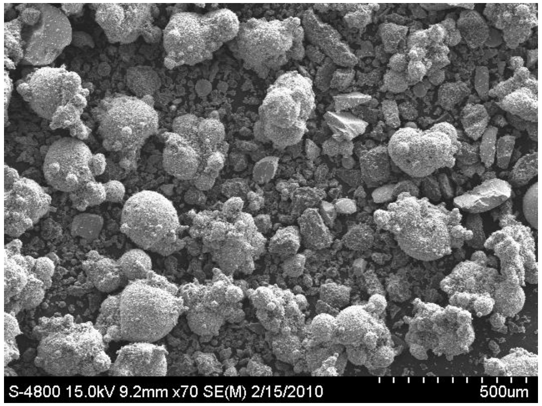
Our Experiences

Material selection
- × high cost metal-Ni/Cu
- _Low cost metal: Fe_2O_3
- ✓Natural material: Ilmenite
- ✓Waste material: red mud

Performance improvement
- ✓Addition inert material
- ✓Granulation

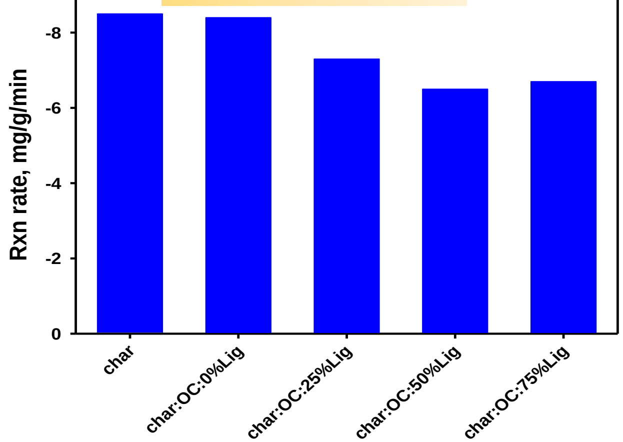
Water Vapor Effect on Char Combustion



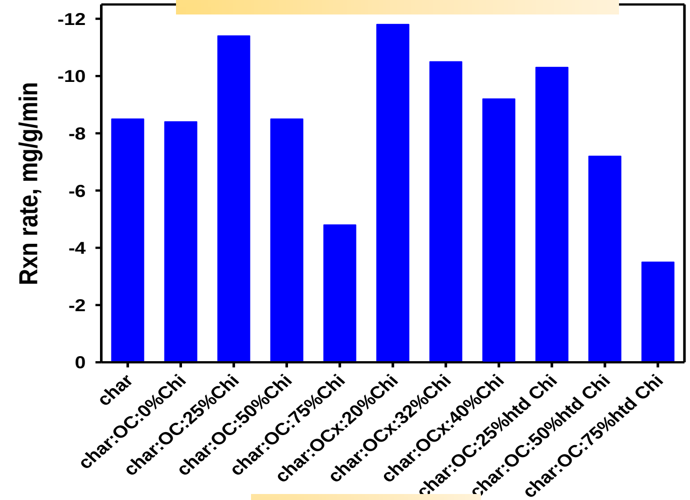


Effects of Different Ash on Reduction Rate

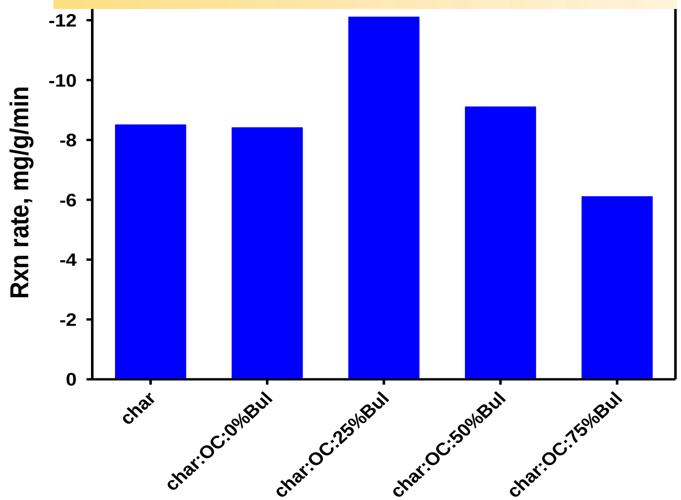
Texas-lignite



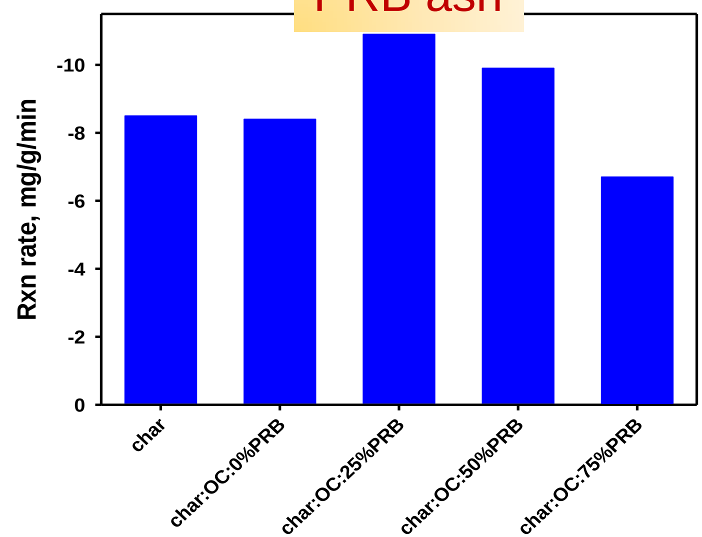
China- bituminous



Bulgarian –sub bituminous

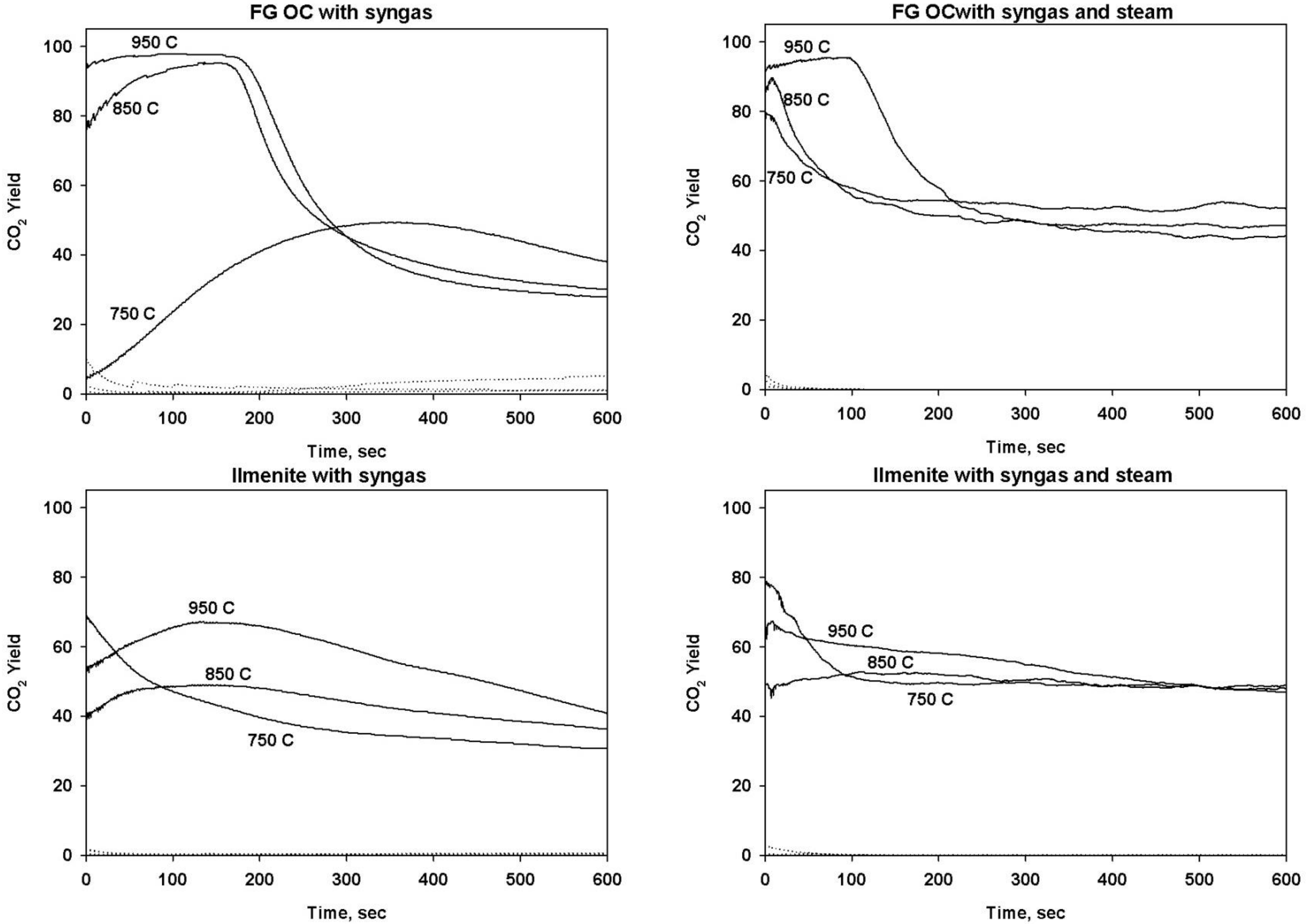


PRB ash



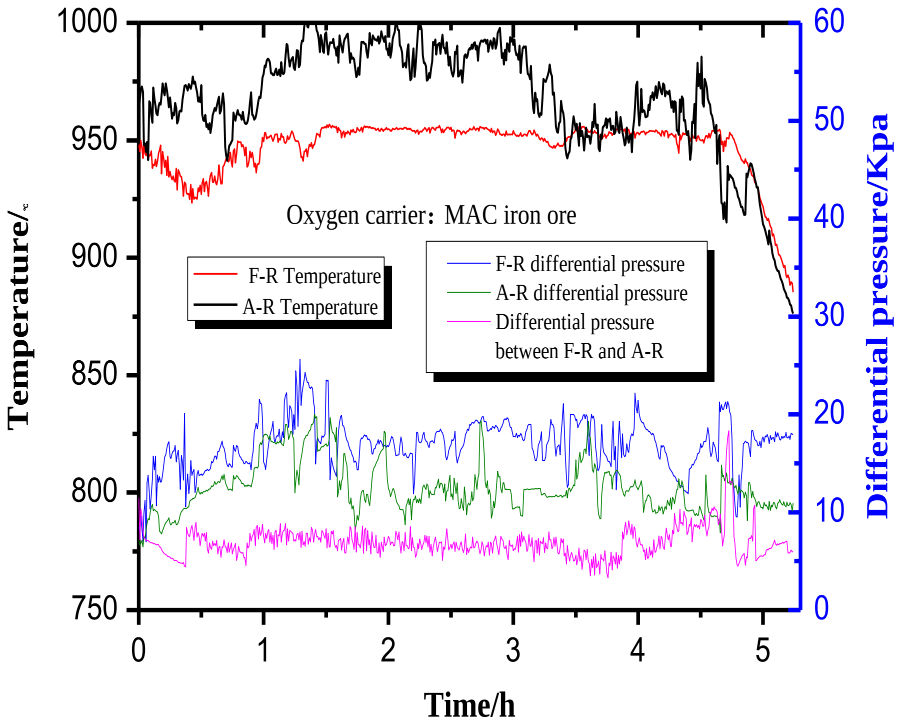
Ash is unavoided as well

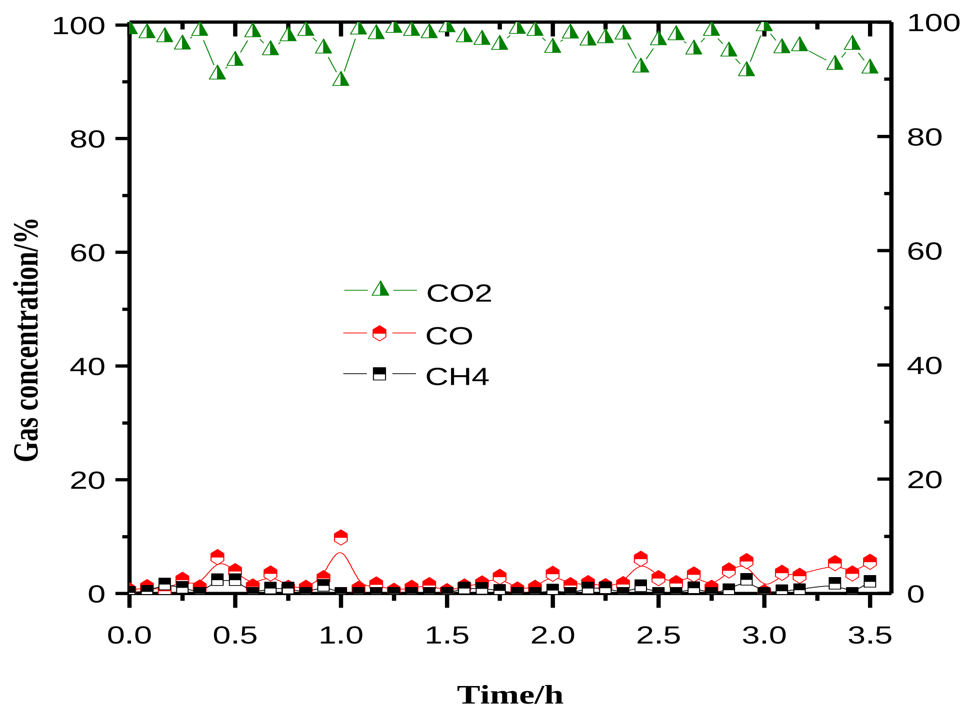
Bench Scale Comparative Study: Synthetic Iron OC vs. iron ore Ilmenite



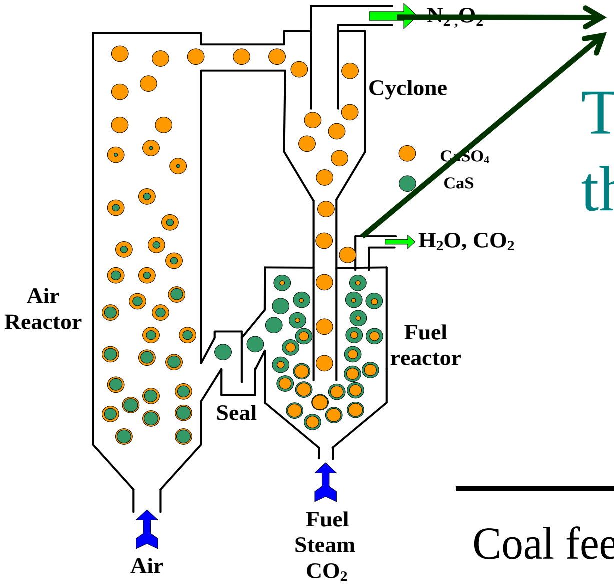
Pilot-Scale Experimental at SEU

- Experiments were conducted at the operating pressures of 0.1, 0.3, 0.5 MPa with MAC iron ore as OC and Shenhua bituminous coal as solid fuel. It has been operated for totally 19 h with stable operation.





OC Cost is Matter!



OC loss

The cost of OC is 15~28% of the operation cost of the unit!

Coal feed rate(FR)	kg/h	12
Steam flow rate (FR)	steam/coal (wt/wt)	2.2-3.0
Air flow rate (AR)	m^3/h	105
Bed temperature in FR/AR	^oC	950/970
Combustion efficiency	%	92.8
CO_2 capture concentration	%	>92
Loss of oxygen carrier	kg/h	1.35-2.66

Tasks

Task	Name
1.0	**Project Management and Planning**
2.0	**Basic Process Specification and Design**
3.0	**Process Simulation of Proposed Heat Integrated Combined Cycle**
4.0	**Sizing and Cost Analysis Associated with PCLC island**
5.0	**Technical and Economic Analysis for Proposed Combined Cycle**

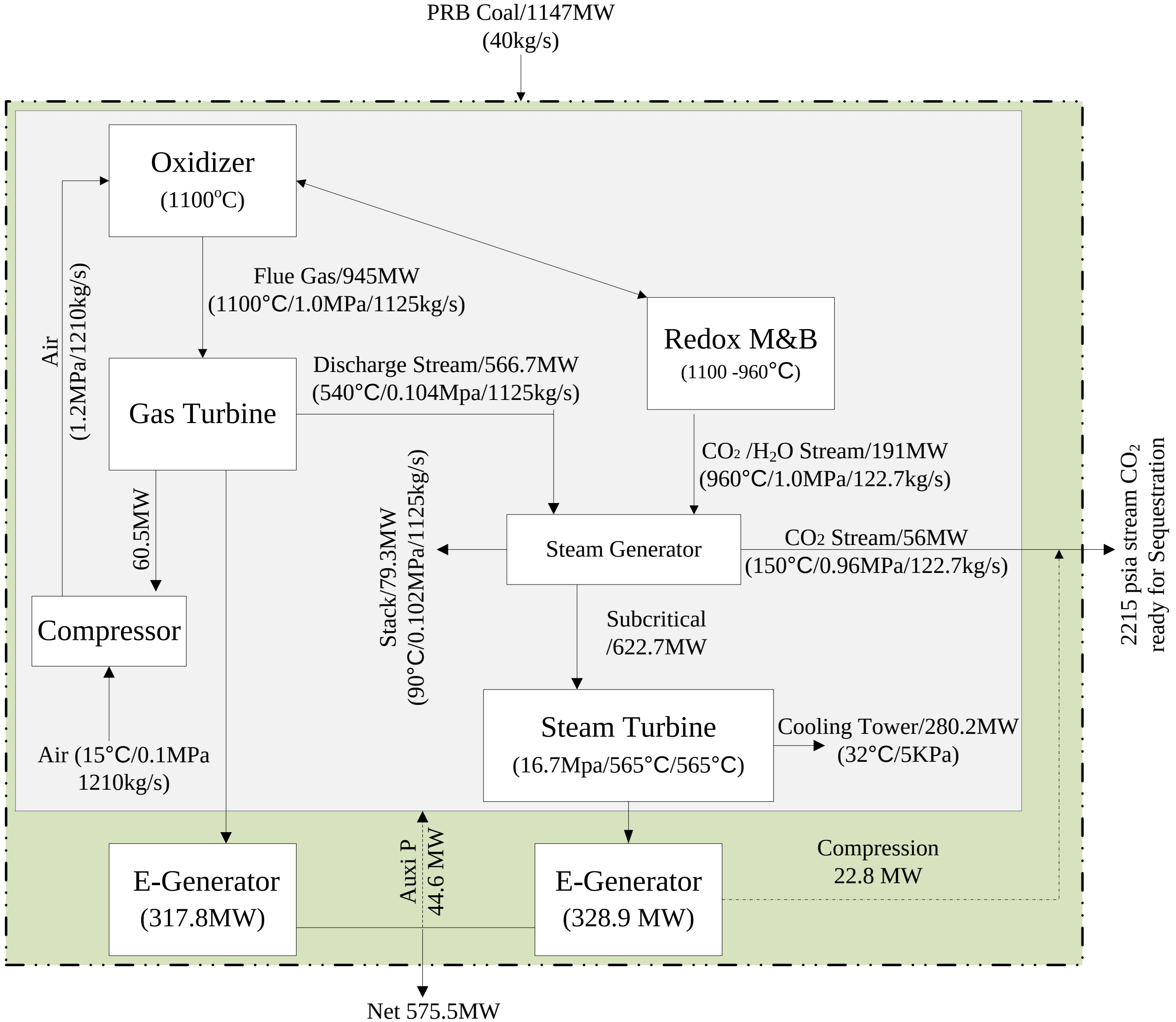
Task 1. Basic Process Specs and Design

- **POWER PLANT OUTPUT (net): ~550MWe**
- **PLANT CAPACITY FACTOR – 80%**
  - Most of equipment in power generation side are commercial available from American suppliers
  - Mature technologies (PCFB, bubbling/moving bed) will be adopted in PCLC island
- **Fuel**
  - Subbituminous Rosebud PRB coal
- **SITE CHARACTERISTICS**
  - Middle west
- **Plant configuration and major equipment list**
  - One pressurized circulating fluidized bed air reactor (1 × 100%)
  - One two-bed pressurized fuel reactor (bubbling and moving) (1 × 100%)
  - Two gas turbines (2 × 50%)
  - One heat recovery steam generator (1 × 100%)
  - One steam turbine (1 × 100%)
  - Two in-line ceramic filters (2 × 50%)

Design Base - PCLC

PCLC Operation Pressure	**1.1MPa**
Fuel Reactor	**Down flow moving-bed + Bubbling Bed (1100 – 950 ^{o}C, 5-10 minutes)**
Air Reactor	**Circulating fluidized bed (1100 ^{o}C, 10-20 seconds)**
Oxygen Carrier	**Alumina supported iron based /red mud oxygen carrier**

Preliminary Energy and Mass Balance



- Two GE 7FA (169 ~211 MW)
- One GE steam turbine (300 ~ 350 MW)

Task 3. Aspen Simulation

- **Property Method**
  - Peng-Robinson Method
    - Circulating Fluidized Air Reactor
    - Redox-Bubbling and Moving reactors
    - Compressor and Gas Turbine
    - CO_2 Compression
  - Steam Tables
    - Steam Turbine
    - Heat Recovery Steam Generator
- **Key Components**
  - Redox moving bed fuel reactor – rate-based *RPlug* based on known kinetics
  - Redox bubbling bed – *RStoic* with pre-determined conversion rate
  - Air reactor – *RBatch* with known kinetics
  - Fuel reactor – *Rstoic*
  - Gas turbine – Compr block
  - Steam turbine – *Compr* block specified by stage efficiency
  - Ash separation – ESP block with mechanical filter

Task 4. Sizing and Cost Analysis

- **Sizing of PCLC Island**
  - Based on the results from 550 MW process simulation model
  - Major components of PCLC sizing by UKy and SEU
- **Capital cost estimation (Jim from WP)**
  - In-house proprietary parametric models from WP
  - ICARUS from Aspen Tech
- **O&M cost estimation**
  - Consumable consumption rates based on Design Basis Report
  - Man power estimates developed by UKy
  - General consumables costs based on DOE report escalated to June 2012 dollars
  - Supercritical technology descriptions and costs in DOE report as basis for the state-of-the-art generation facilities

Task 5. T-E Analysis

- **Sensitivity Study**
  - Focused factors
    - PCLC Island operation pressure
    - cost of oxygen carrier
    - excess air factor
  - 4 cases

	Operation Pressure (MPag)	Oxygen Carrier	EHX/Excess air
Case 1 (Base case)	1.0	Red mud oxygen carrier	No EHX, excess air factor 3.2
Case 2	1.2	Red mud oxygen carrier	No EHX, excess air factor 3.2
Case 3	1.0	Synthetic oxygen carrier	No EHX, excess air factor 3.2
Case 4	1.0	Red mud oxygen carrier	With EHX, Excess air factor 1.75

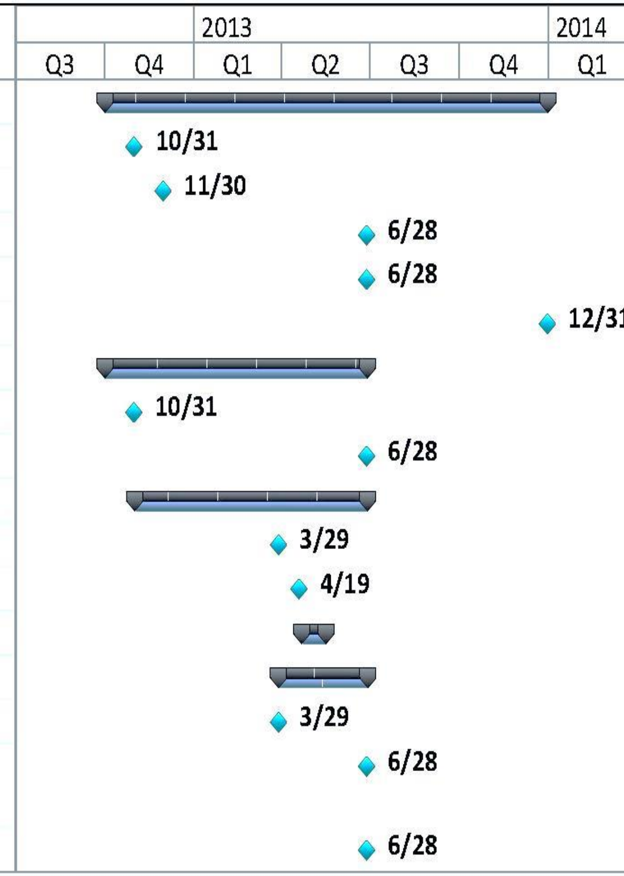
Phase II Approach

- **Large Quantity Oxygen Carrier Production**
  - Produced by spray-drying facility at Süd-Chemie
  - 1000 lb/batch
  - Synthetic OC from commercial Fe_2O_3 and Al_2O_3 powder
  - Red mud OC from direct red mud slurry spray granulation

- **200 kW pilot scale pressurized moving bed Redox**
  - Will be located at CAER-UKy
  - Coupled with the pilot scale gasifier at CAER-UKy
  - Detailed engineering design by UKy and SEU
  - Parametric testing campaign at CAER-UKy
  - Long term testing campaign at CAER-UKy
  - Update Technical-Economic Analysis with Worley Parsons

Schedule and Milestones

Task Name	Start	Finish
1.0 Project Management and Planning	**10/1/12**	**12/31/13**
Kickoff meeting complete	10/31/12	10/31/12
PMP revision complete	11/30/12	11/30/12
Phase I Draft Final Report	6/28/13	6/28/13
Phase II Application	6/28/13	6/28/13
Phase I Final Report	12/31/13	12/31/13
2.0 Basic Process Specification and Design	**10/1/12**	**6/28/13**
Submit Design Basis Document	10/31/12	10/31/12
Engineering Design for Proposed 200kWth Pilot-scale Facility	6/28/13	6/28/13
3.0 Process Simulation of Proposed Heat Integrated Combined Cycle	**11/1/12**	**6/28/13**
Complete process model draft for interim technical status report	3/29/13	3/29/13
Process model complete	4/19/13	4/19/13
4.0 Sizing and Cost Analysis Associated with PCLC island	**4/22/13**	**5/16/13**
5.0 Technical and Economic Analysis for Proposed Combined Cycle	**3/29/13**	**6/28/13**
Technology Engineering Design Interim Report	3/29/13	3/29/13
Submit Final Phase I Technology Engineering Design and Economic Analysis Report	6/28/13	6/28/13
Submit Phase I Technology Gap Analysis Report	6/28/13	6/28/13



Deliverables

1. Technology Engineering Design Basis Report (due October 31, 2012)
2. Technology Engineering Design Interim Report (due March 31, 2013)
3. Final Phase I Technology Engineering Design and Economic Analysis Report (due June 29, 2013)
4. Final Phase I Technology Gap Analysis (due with Phase II application by June 29, 2013)
5. Phase I Topical Report (Draft Final Report) (due 6/29/2013)
6. Phase II Application (due 6/29/2013)
7. All other deliverables as defined in the Federal Assistance Reporting Checklist including the Phase I Final Report (due no later than 12/31/2013)

Budget

- Project Funding:
  - $ 599,687 from DOE NETL
  - $ 155,613 cost share from team
    - $ 150,613 from UKy
    - $ 5,000 from SEU
- 1-year project consisting of 1 budget period with possible selection for Phase II